New Amorphous Ultra-thin $Ti_xAl_{1-x}O_y$ Alloy Oxide Layers For Next Generation of High-K Gate Dielectrics

Lijuan Zhong[1], Wei Fan[1], Bernd C. Kabius[1], Li Yan[2], Eugene A. Irene[2], Orlando Auciello[1]

[1]Materials Science Division-Argonne National Laboratory

[2]University of North Carolina-Chapel Hill

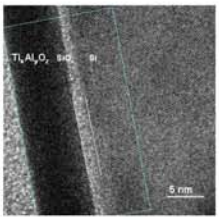
Motivation

Investigate an alloy of TiO_2 and Al_2O_3 in thin film form as a novel amorphous material with unique thermodynamic and kinetic oxidation and electrical properties for application as high-K gate dielectrics in the new generation of nanoscale CMOS devices

Major Accomplishments

Developed a low temperature sputter-oxidation process to make ultra thin $Ti_XAl_{1-x}O_y$(TAO) layer with practically no interfacial SiO_2 layer with good electrical properties for application to high-K dielectrics

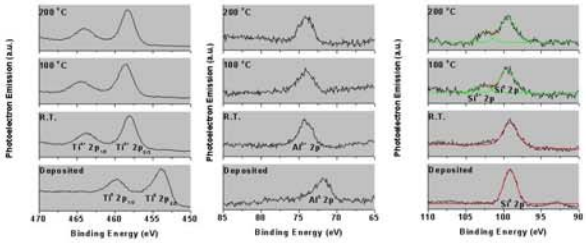
Experimental Approach: R.T. sputter-deposition of thin TiAl alloy films followed by *in situ* oxidation using atomic oxygen

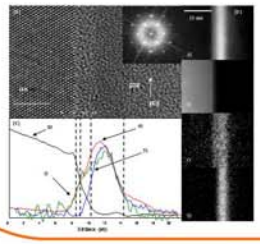


Sputter-deposition of metallic TiAl layer on Si + oxidation at 500 ºC

Interfacial SiO_x ~ 1 nm

XPS analysis shows that R.T. oxidation of TiAl layer inhibits formation of SiO_2 interfacial layer

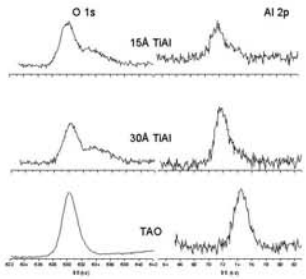




HRTEM (a) and EELS analyses ((b) elemental maps; (c) integrated line scans)

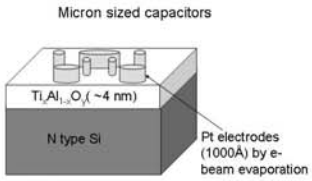
- An enriched Al and O layer between the TAO film and Si
- Only subatomic thin SiO_x interfacial layer

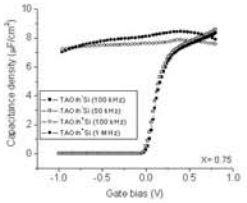
Unique Thermodynamic and Kinetic Oxidation of TAO alloy assisting the reduction of SiO_x interfacial layer



XPS analysis shows preferential bonding of O to Al, partially reducing the SiO_x layer on the Si surface, forming an AlO_x interfacial layer

***C-V* characteristics of the TAO-based MOS capacitors**

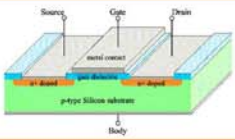




High accumulation capacitance densities (7.7 – 8.3 μF/cm²), corresponding to a record thin high-K layer with *EOT* < 0.5 nm

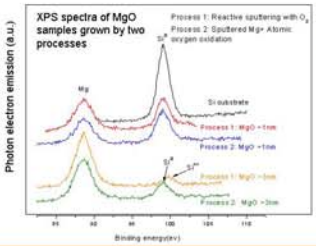
Impact

Development of robust TAO atomically thin layer as high-K gate dielectrics may enable the next generation of nanoscale CMOS Devices



Future Work

- **Optimize bandgap and density of trapping states at TAO-Si interface**
- **Investigate effects of introducing an atomically thin MgO(~1nm) layer into the TAO-Si structure on the overall electrical properties of TAO-MgO films for high K dielectrics**
- **Investigate effects of compositional changes on the TAO layer**



sputter-oxidation vs. reactive sputtering of MgO layer

The lack of Si^{n+} peak in process 2 shows its advantage to suppress the formation of SiO_x interface

O. Auciello, W. Fan, B. Kabius, S. Saha, J. A. Carlisle, R.P.H. Chang C. Lopez, E. A. Irene, R. A. Baragiola, Appl. Phys. Lett. 86, (2005) 031902.

ARGONNE NATIONAL LABORATORY

This work was supported by the U.S. Department of Energy, Basic Energy Sciences, under contract W-31-109-ENG-38.

THE UNIVERSITY OF CHICAGO

Office of Science U.S. DEPARTMENT OF ENERGY